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RESEARCH REPORT

OFF-BOARD EXPENDABLES: AN AID TO AIRCRAFT SURVIVABILITY

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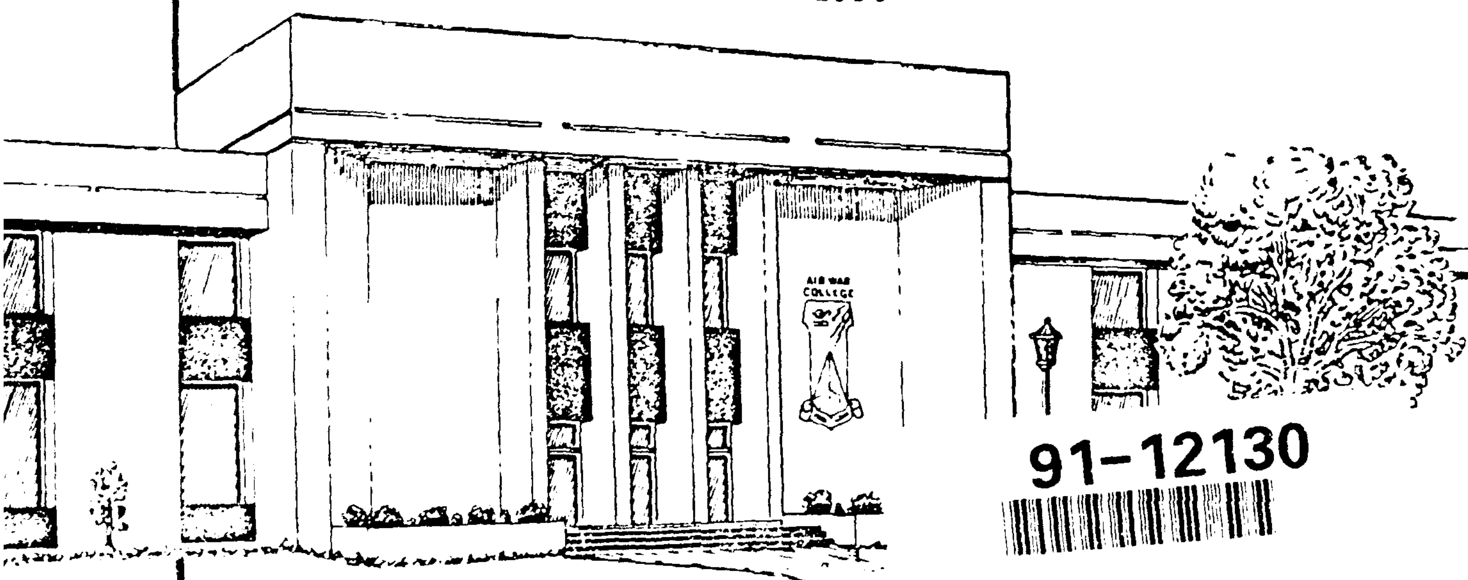

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OFF-BOARD EXPENDABLES:
AN AID TO AIRCRAFT SURVIVABILITY

by

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A DEFENSE ANALYTICAL STUDY SUBMITTED TO THE FACULTY

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DISCLAIMER

EXECUTIVE SUMMARY

During World War II, off-board expendables in the form of chaff, significantly reduced Allied bomber losses to radar guided anti-aircraft artillery. From World War II on, the United States has employed Electronic Counter-Measure (ECM) techniques on various bomber, fighter, cargo and special mission aircraft to enhance their survivability.

The primary threats to aircraft today are the highly sophisticated radar and infrared guided air-to-air and surface-to-air missiles. Advances in computer hardware and data/signal processing techniques have enabled these missiles to increasingly distinguish between a target aircraft and current generation self-protection on-board ECM and off-board expendables.

One potential counter to these smart missiles is a new self-protection ECM technique called the towed decoy. The towed decoy acts much like a target towed behind an aircraft in that it presents a threat missile with a better target than the intended target aircraft. The same technology advances that have made smart missiles possible, have also made small, relatively inexpensive towed radio frequency and infrared decoys practical.

Towed decoy systems are currently in various stages of research and development. Articles such as those at reference one tend to be very market oriented and stress only the positive aspects of towed decoy systems. Upon a comparison with previous expendable systems and tow target systems, the author feels that there are design, operational and acquisition concerns that should be addressed during the acquisition cycle. This study identifies these concerns, provides an assessment as to why each is important, and concludes with recommendations on how to resolve or minimize them during the development process.

This study discusses two main types of towed decoy systems. The first is based on a retrievable decoy with a dispenser that reels out and reels in the decoy, and the second is based on a non-retrievable decoy with a dispenser that fires out the decoy then severs its towline when finished with it. Even though the first system recovers its decoy, both types of systems still fall under the category of "self-protection" expendables. Because there are so many variables that must be considered in deciding which is most applicable for a specific aircraft application, the intent of this study is to present information which may reduce costs and risks for towed decoy system designers and decisionmakers, not to advocate a particular system.

BIOGRAPHICAL SKETCH

Lt Colonel Jeffrey Knieriemen (BSEE, University of Toledo, OH; and MBA, Rensellaer Polytechnic Institute, NY) received his Navigator wings in Dec 1973 and flew as a B-52G Electronic Warfare Officer at Griffiss AFB, NY, from 1975 through 1977. From 1977 through 1980 he was a Project Engineer at the Intelligence and Reconnaissance Division of the Air Force Systems Command, Rome Air Development Center (RADC), Griffiss AFB, NY. From 1980 through 1984 he was the Program Element Monitor (PEM) and Systems Command Technical Officer (SYSTO) for various intelligence and computer technology research and development programs for the HQ AFSC Director of Science and Technology. Following graduation from the Defense Systems Management College in 1984, he was assigned to the AFSC Aeronautical Systems Division at Wright-Patterson AFB, OH, and became the Program Manager of, and in 1987, the Division Chief for, various Air Launched Cruise Missile and other strategic system programs in the Air Launched Cruise Missile Special Projects Office. Lt Colonel Knieriemen is a graduate of Air War College, class of 1990.

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CHAPTER I

INTRODUCTION

During World War II, the Allies employed Electronic Counter-Measure (ECM) techniques to enhance the survivability of bomber aircraft from German radar directed threats. Since then, ECM techniques have been greatly expanded, and today counter many types of radio frequency (RF), infrared (IR), milli-meter wave (MMW), and laser guided and/or directed threats.

ECM techniques fall into the category of on-board or off-board, and active or passive. Note that the first category of the following ECM techniques has its main goal of denying initial detection of the aircraft. The second and third categories depend on the hardware, but can be used to protect the aircraft by either jamming and/or deceiving threat systems after initial detection so they cannot launch missiles, or once missiles are launched, to create a miss distance that allows the aircraft to survive. The fourth category is usually only employed as a last resort by an aircraft, and its only goal is to create survivable miss distances. ECM techniques employed after a threat missile is launched are called 'terminal' or 'self-protection' countermeasures.

a. Category 1: On-board passive ECM techniques include the reduction of giveaway emissions and reflections from the aircraft. These include radar, radio, sound, light and infrared and are termed "stealth". For instance, to passively protect an aircraft from radar detection, one might use a combination of body shaping to shield reflective surfaces (eg. engine compressor stages), reflective surfaces to direct the radar energy somewhere other than directly back to the tracking radar, and radar absorptive materials to trap and absorb the radar energy so it does not reflect back to the tracking radar. {2:71-72}

b. Category 2: An RF transmitter and antenna system or an IR transmitter and lens mounted in, or on, the aircraft are examples of on-board active ECM systems. One prominent example of an active on-board ECM system is the AN/ALQ-161 carried by the B-1B bomber. This is the first operational system to integrate ECM tasks like threat analysis and warning, system control, expendables, and jamming. The AN/ALQ-161 has over 100 line replaceable units and weighs over 5000 pounds. The design goal was to counter early warning, ground controlled intercept, and threat radars including surface to air, air-to-air and antiaircraft artillery (AAA) radars, in the frequency range from 0.2 gigahertz (GHz) to somewhere in K-band (10.9 - 36.0 GHz). {2:70,71}

c. Category 3: Aluminum foil or metalized fiberglass strips called chaff, fired in front of the aircraft by rockets, or ejected into the airstream alongside the aircraft are examples of off-board passive ECM systems. Today, most chaff dispenser systems, like the AN/ALE-45 for the F-15, are designed for self-protection of the dispensing aircraft. In the past, however, systems like the AN/ALE-36, 37, and 38/41, were designed as bulk chaff dispensers. High speed fighter aircraft carrying these dispensers would precede other aircraft into a threat defended area and lay a chaff corridor. As long as the following aircraft stayed within the chaff corridor, they were relatively safe from radar directed ground threats. The US successfully used these systems to lessen B-52 bomber losses over North Vietnam. (4:839)

d. Category 4: Small RF transmitters and IR flares ejected from the aircraft are examples of off-board active ECM. Of the two examples, the least well known is the expendable RF transmitter. In the mid-1970's, details emerged on an active expendable decoy called the AN/ALQ-134. This decoy weighed less than one pound, and reportedly used lithium batteries to power a microstrip receiver/transmitter. Once deployed it unfurled a transmission antenna attached to a drogue chute and a parawing. It is probably no longer in production or use. An expendable decoy system known to be in use today by the US Navy is the POET or Primed Oscillator Expendable Transponder. This system, currently procured at the rate of 2300 per month, is sized to fit the standard Navy 1.4 inch by 1.63 inch chaff/flare launch module. Once deployed, the POET, believed to retransmit missile guidance radar signals, presents the missile with a more attractive but false target. One other expendable decoy system is the GEN-X or General Electronic Expandable. The GEN-X system, currently under development, has a decoy which is comprised of an antenna, receiver, transmitter, signal processor, input frequency limiter, power amplifier, local oscillator, controller, modulator and phase-lock loop circuitry. The GEN-X decoy is only six inches long with its fins folded and miniaturization has reportedly been achieved through the use of gallium-arsenide monolithic microwave circuitry. Like the POET, the GEN-X is designed to decoy RF homing missiles by mimicking the tracking radar signal, but at a signal strength high enough to make the decoy more attractive than its launch aircraft. {2:69}

Some ECM hardware and techniques, like stealth for example, are intended to delay, confuse, and deceive the enemy so he is unable to effectively employ his weapon systems. On the other hand, self-protection ECM, like the use of most active and passive off-board expendables, is specifically designed to protect the aircraft when it is actually under attack.

Today, the most lethal threats an aircraft faces are radar guided/seeking and infrared (heat) seeking air-to-air missiles (AAMs) and surface-to-air missiles (SAMs). These missiles fall into three main categories:

a. Category 1: Command guided. A command guided missile depends solely on a ground tracking radar for guidance to its target. Basically, the missile control surfaces are controlled via a radio link to the tracking radar.

b. Category 2: Active. Active missiles transmit their own signal toward their target then home on reflections from the target. Examples of active RF missiles include the Navy air-to-air, Phoenix and the Air Force air-to-air, AIM-120 Advanced Medium Range Air to Air Missile (AMRAAM). Note that active missiles fall into the 'launch and leave' class. This means that the launching aircraft or ground system can concentrate on the next target soon after missile launch and the missile takes over and accomplishes its own intercept. Due to their launch and leave nature, I include infrared homing missiles, like the Air Force air-to-air, AIM-9 Sidewinder, in this category even though IR guided missiles do not radiate energy on their own, or track on reflected energy.

c. Category 3: Semi-active. Semi-active missiles home in on radar or other signal energy that reflects off their target. For these missiles to complete their intercept, the tracking radar or signal must illuminate the target continuously. These missiles are not of the launch and leave type. Examples of semi-active RF missiles include the Air Force air-to-air, AIM-7 Sparrow and the Army surface-to-air, Hawk.

In addition to the three main categories above, some missiles have an electronic counter-countermeasure or back-up seeking mode called 'home on jam' (HOJ). Missiles with the HOJ feature will home in on a strong jamming signal if it loses its desired target reflection. For this reason, on-board ECM hardware can be a detriment during the missile end-game.

Against missile threats, the purpose of self-protection expendables is to create a large enough miss distance that the aircraft survives even if the warhead detonates nearby. The magnitude of the required miss distance is a complex function of the missile fuse, warhead size and blast pattern, and vulnerability of the specific aircraft. Advances in computer hardware and data/signal processing techniques have enabled the active and semi-active missiles especially, to distinguish between target aircraft and current self-protection on-board ECM and off-board expendables.

One potential counter to these smart missiles is a self-protection ECM technique called the towed decoy. The towed decoy electronically functions much like the POET or GEN-X free fall expendable in that it tries to present a threat missile with a better target than the intended target aircraft. The difference is that the towed decoy remains tethered to the aircraft and follows it through all altitude, airspeed and direction changes. The same technology advances that have made smart missiles possible, have also made small, relatively inexpensive, towed radio frequency and infrared decoys practical.

This study discusses two main types of towed decoy systems. The first, based on a retrievable decoy, uses a dispenser which reels out and reels in the decoy, and the second, based on a non-retrievable decoy, uses a dispenser which fires out the decoy then severs its towline when finished with it. Although the first system "recovers" its decoy, both systems are "expendable" or "off-board" self-protection ECM systems. Because so many variables must be considered in deciding which is most applicable for a specific aircraft application, the intent of this study is not to advocate a particular system, but to present information which may reduce costs and risks for towed decoy system designers and decision makers.

Towed decoy systems are currently in various stages of research and development. Articles like reference one which describes a Tracor towed RF decoy (called the "Big Boy") and a Tracor towed IR decoy, tend to be marketing oriented and stress only the positive aspects of towed decoy systems. Upon comparing generic towed decoy systems with previous expendable systems and tow target systems, I feel that there are several fundamental design, operational and acquisition concerns which should be addressed during the towed decoy system acquisition cycle.

Chapter two discusses the history of towing various hardware behind aircraft. It compares aerial tow targets and towed decoy systems. Chapter three analyzes the importance of expendables and why minimizing the velocity difference between the aircraft and the expendable is important. Chapter four covers the similarities and differences between a free-fall expendable system and a towed decoy system. Chapter five (design concerns), chapter six (operational concerns), and chapter seven (acquisition concerns) are the key chapters of this study. These chapters identify and analyze key design, operational and acquisition concerns, provides an assessment as to why each concern is important, and concludes with recommendations on how to resolve or minimize them during the development process.

CHAPTER II

HISTORY OF TOWED DECOY SYSTEMS

Towing "things" behind aircraft is not new. In the civilian world, most of us have seen, at one time or another, advertising banners or birthday greetings being towed behind aircraft. In the military world, as early as World War II, aircraft accomplished "tow" missions. During the D-Day invasion, for example, Allied transport aircraft towed gliders (often two at a time) fully laden with troops and materials behind German lines. Recent examples include:

a. Air-refueling drogue hoses and nozzles deployed from USAF HC-130P transports, USAF KC-10A tankers, and USN KA-6 tankers.

b. Magnetic anomaly detectors towed behind certain US Navy antisubmarine warfare helicopters.

c. Aerial gun and missile practice targets towed by high performance jet aircraft.

The last category, aerial practice targets, is obviously the most relevant to towed decoy expendable systems. It has been common for many years to conduct air-to-air and surface-to-air target practice using an aircraft towed banner or radar enhanced tow target. For safety, the tow target is usually towed thousands of feet behind the towing aircraft. Representative of recent tow targets include the Navy Low Cost Tow Target (LCTT) and the Navy TDU-34 tow target. These tow targets were designed to be carried, launched, towed, and retrieved by F-4 aircraft. These six to nine foot long tow targets generally have their radar cross section enhanced by physical means, like passive radar corner reflectors, to look like a generic full size aircraft. They may also have battery operated tracking beacons and/or missile miss distance indicator hardware internally installed. {Note, these have been personally observed and while a reference could not be found they are closely related to tow targets discussed in reference 4:561-565}

There are several differences between tow targets and towed expendable self-protection decoys. Key similarities and differences include:

a. The towed decoy must follow the towing aircraft through high "G" turns and maneuvers. This is required so high performance aircraft will not suffer mission limitations either when they are under attack or when they are towing a deactivated decoy. Tow targets are commonly towed in straight and level flight for safety reasons.

b. The towed decoy must fly as close as a few tens to a few hundreds of feet behind the aircraft in what is often very turbulent air. This is required to keep both the aircraft and the decoy in the attacking missile's seeker field of view during crucial stages of seeker lock-on. Again for safety, tow targets are towed thousands of feet behind the towing aircraft where they can be positively and distinctly identified. At these distances the tow target is in a relatively stable, nonperturbed airmass.

c. Both the towed decoy and the tow target must have an IR, RF, etc. signature that looks just like, but much bigger than the aircraft. For the decoy, this is required to keep the missile seeker locked-on to the decoy until it is too late for the missile to correct course and hit the aircraft.

d. The towed decoy may need to be electronically controllable from the towing aircraft. This is required so the RF or IR decoy can be turned "on" when a threat is present, and "off" when the threat is passed. An alternative form of control is to have the decoy deployed in the "on" state, then reel it in or dispose of it entirely when the threat is gone. In general, neither an RF nor an IR decoy should be left in the "on" state when the threat is gone. For the IR decoy this would result in a waste of fuel and/or chemicals. For the RF decoy this would result in broadcasting the aircraft position prematurely to the next set of threats. A similar requirement exists to turn tow targets on and off, but the reason is enhanced mission time, not towing aircraft survival.

e. The towed decoy needs to provide a small physical target to an attacking missile so that there is a small probability of the decoy being "killed". This is required so that fewer of each decoy type need to be carried to complete a specific mission. While it is nice to build survivable tow targets so they can be reused, this effect is usually gained by attacking them with unarmed missiles. These missiles usually have a telemetry and/or beacon system installed in place of the warhead. Often there is a corresponding beacon mounted inside the tow target and the miss distance is calculated.

f. The towed decoy employed by stealthy aircraft, must provide a low RF, IR, MMW etc. signature when deployed but in the "off" state. As mentioned above, an aircraft should not tow around an active, or "on", decoy when there are no threats present. For those cases where the decoy is designed to be turned "off" by the aircraft and retained in tow behind the aircraft until the next threat is encountered, the decoy in its "off" state should be at least as stealthy as the towing aircraft and not prematurely reveal the presence of the aircraft to the next set of threats. Obviously the tow target has no similar requirement.

g. The towed decoy should present as low an aerodynamic drag as possible when it is under tow. This is required because every source of drag to an aircraft means decreased mission range. Because of safety and all the miscellaneous hardware often installed inside the tow target, drag may be of general concern, but not from the aircraft's wartime mission role.

The same technology that has led to the capability to produce super smart missile systems, POET and GEN-X free-fall decoys, and Tracor's Big Boy and IR towed decoy systems also provides the capability to develop operational towed decoy systems.

CHAPTER III

IMPORTANCE OF TOWED DECOY SYSTEMS

There are two major problems with non-towed or free-fall expendables. The first problem is timing expendable deployment so that the minimum number of expendables are used for each threat engagement. This is not because the expendables are expensive, but that only a limited number can be carried in each dispenser.

To understand why free-fall expendable deployment timing is important, consider the following representative missile intercept scenario. At 0.8 mach at sea level, an aircraft will pull away from a free-fall expendable at the rate of nearly 1130 feet per second. In an impractical but worst case, if a missile is launched directly off the target aircraft beam (90 degrees left or right of the nose), and the missile seeker has a 500 foot field of view at its point of last decision as to which 'target' to follow, over two expendables per second will have to be deployed to ensure that the missile will decide to follow the expendable. A dispenser of thirty flares, for instance, will last less than fifteen seconds. If there is much uncertainty as to when, to the second, to start and stop free-fall expendable dispensing, the dispenser(s) may be empty before the aircraft returns to friendly airspace.

The problem with timing and running out of expendables can be compensated for by:

a. Installing more dispensers on the aircraft -- this means adding weight and using limited aircraft space.

b. Installing a very sensitive, accurate, all-aspect radar on the aircraft to warn of approaching missiles -- this means adding weight and using limited aircraft space, plus depending on a system that may erroneously deploy due to "false alarms" or not deploy expendables when they are really needed due to "missed detects".

c. Terminating the mission once the remaining number of expendables reach an unacceptable level -- this may be the safest solution but may occur too late in the mission for the aircraft to egress safely, or preclude accomplishment of an critical mission.

The second major problem with free-fall expendables is that the expendable starts to slow down as soon as it departs the aircraft and therefore has a velocity that is increasingly different from the dispensing aircraft. Gains in miniaturization of electronic circuits and computer capabilities currently allow active and semi-active RF guided missiles and IR homing missiles to be built with far more signal processing capability than before. Key to these new capabilities are electronic counter-countermeasure (ECCM) circuits inside the missile which can increasingly discriminate between the velocity of the target the missile was launched at, and free-fall expendables/decoys that may try to draw the missile away from its intended target. The discrimination process is done by doppler processing much the same as that done by ground and airborne radars that detect and track moving targets in the midst of clutter, or non-moving radar returns.

The problem of differing velocities can be overcome by propelling the expendable along a course parallel to the aircraft. Propulsion can be internal to the expendable as was done by the now obsolete AN/ALE-25 forward fired chaff rocket, the now obsolete ADM-20 Quail Decoy, or the Brunswick Tactical Air Launched Decoy (TALD); or propulsion can be provided by the aircraft and a towline as done by Tracor in their RF and IR towed decoys.

The AN/ALE-25 forward firing chaff rocket system was designed to protect Strategic Air Command B-52 nuclear bombers from radar guided threats. A rocket dispenser was mounted on a pylon under each wing. Each 2.75 inch folding fin rocket was loaded with chaff that explosively deployed several hundred feet in front of the B-52.

The ADM-20 Quail Decoy, operational from 1961 through 1978, was also designed for, and carried by, Strategic Air Command B-52 nuclear bombers. The Quail was nearly 13 feet long, over 3 feet high, weighed 1100 pounds, and had a wingspan of nearly 6 feet when in flight. It had a top speed of nearly 600 mph over ranges varying from 400 miles at high altitudes and 39 miles at low altitudes. Essentially, it was designed to match a B-52's speed, altitude, radar signature, IR signature and flight profile. Each B-52 could carry up to four Quails in the bomb-bay along with other nuclear weapons. The Quail, however, was not a self-protection decoy. Its main purpose was to be launched during the initial penetration of enemy airspace to create multiple targets and saturate the Soviet air defense system. (2:69-71)

The Brunswick self-propelled TALD began development under company funding in 1973. The company's goal was to equip, and protect, fighter aircraft like the F-4. Although government testing was successful, the US Air Force and Navy showed no interest in acquiring the decoy. The design was subsequently sold to the Israelis who used the TALD, now designated the Samsom, in 1982 over the Beka Valley. The US Navy bought 100 Samsons for evaluation and later placed orders for about 1000 more Americanized Samsons. The decoy has folding wings, a cruciform tail, is about seven feet long, ten inches in diameter, and has a wingspan of nearly five feet. The TALD uses a solid state transponder to re-radiate radar signals. The flight range of the TALD is undisclosed. (2:71)

The towed decoy, as represented generically by the Tracor Big Boy and IR decoys, offers a promising alternative to both free-fall expendables and to self-propelled expendables. These demonstration systems show the feasibility of carrying a fairly small ECM system that has high utility as a self-protection system. {1:36-38} Modern self-protection decoys need to match the aircraft's velocity and course which is difficult if the aircraft is maneuvering, its radar and IR signatures, and stay in the air for at least tens of seconds to ensure that one expendable will do the whole job of protecting the aircraft. Note that previous examples show that the state of the art is capable of developing self-propelled decoys, but they are too large to carry very many, and they may not perform the self-protection function very well in high threat environments where the aircraft is maneuvering.

CHAPTER IV

FUTURE EXPENDABLES, THE TOWED DECOY SYSTEM

Expendable systems in use today are capable of dispensing mixed loads of chaff, flares and non-towed expendable jammers. Examples of these systems and the aircraft (and helicopters) that use them are:

a. The AN/ALE-39, operational on the following aircraft: P-3C, A-4, F-4, A-6, EA-6B, A-7, AV-8A/B, F-14, and F-18. Also operational on the following helicopters: AH-1, UH-1, CH-46, CH-53, SH-2F LAMPS 1 helicopters. (5:1-2)

b. The AN/ALE-40, operational on F-5E/F, Royal Netherlands NF-5, A-7D, A-10, F-16, F-104, Hunter and Mirage aircraft. (3:839)

c. The AN/ALE-45, operational on the F-15 aircraft only. (7:2)

d. The AN/ALE-47, currently in development and "...is being designed to replace the entire spectrum of front-line countermeasures dispensers used by all services, and also by most Allies." Specifically the AN/ALE-47 will replace the AN/ALE-39, 40 and 45 systems. (8:2)

Expendable systems like those above require the functions usually identified with the following subsystems: (2:17-19)

a. Threat warning. This subsystem may consist of sophisticated threat warning receivers and/or missile warning sensors, or it may be simply visual detection by a crewmember of the launch or approach of one or more missiles.

b. Control. This subsystem monitors the health and status of the dispenser(s) and often of the expendables inside the dispenser(s). It provides the control signals to the dispenser that direct how many expendables to deploy and when to repeat the sequence if required. The control function can be completely automatic or under manual control of the aircrew.

c. Dispenser. The dispenser will hold multiple expendables, usually of different varieties. Each of the two AN/ALE-40 dispensers internally mounted in the F-16, for example, can hold 30 chaff packages, 15 flare cartridges, or a mixed load where two chaff packages are displaced for each flare cartridge installed. Other expendable systems like the AN/ALE-39, can also dispense expendable RF jammers. Generally the expendable is deployed by an explosive device called a pyro or squib. Once the expendable departs the dispenser, it takes basically a free-fall trajectory and can no longer be physically or electronically controlled from the aircraft.

d. Expendable. Since the whole purpose of the expendable is to decoy an incoming missile away from the aircraft and create a miss distance, the expendable is constructed to approximate one or more of the signatures of the aircraft. If the expendable is a flare cartridge, for example, the flare must look like a better target to the incoming IR homing missile than does the heat of the aircraft engine or body surfaces. Currently expendables are single function, or in other words, they are designed to decoy either an RF missile or an IR missile, but not both.

While future expendable systems will require the same functions already identified with threat warning, control, dispenser and expendable subsystems, two of these subsystems, the dispenser and the expendable, will undergo major changes. For future expendable systems, instead of just ejecting an expendable into the airstream, they may deploy an off-board, or expendable, ECM device called a towed decoy which remains attached to the dispenser via a tow line. There are two major categories of towed decoy systems.

The first category of towed decoy system, called the retrievable towed decoy system, uses a dispenser which reels out the decoy to a distance determined to be most effective for a particular threat or class of threats. The expendable remains in tow behind the aircraft as long as needed. When the threat has been passed or avoided, the mission is complete, or the decoy is no longer operational, the towline is wound back up on the reel and the expendable would return to a stowed position.

The second category of towed decoy system is called a non-retrievable towed decoy system. This system uses a dispenser which contains one or more decoys, each tethered to the dispenser by its own cable reel. In operation, the dispenser ejects a decoy into the airstream where decoy aerodynamic drag causes the cable reel to unwind. The cable reel usually contains a braking system to slow the decoy as the reel approaches the end of its cable. As with the retrievable decoy, the decoy remains in tow behind the aircraft as long as needed. Unlike the retrievable decoy system, however, when the decoy is no longer needed, its towline is severed rather than being reeled back in.

Comparing towed decoy systems with non-towed expendable systems, major changes include:

a. For the dispenser and/or control subsystem -- Additional electronics to monitor the health and status of the expendables, both before and after deployment, and to reel out, reel in and/or sever the expendable.

b. For the dispenser -- Towline reels, several hundred feet of towline, brakes to slow/stop the decoy, electric or ram air motors to reel out/in the decoy, towline cutter hardware, and often mechanical arms/tracks to lower or otherwise assist the expendable during deployment/retrieval.

c. For the expendable -- The expendable must not only separate safely from the aircraft, it must be aerodynamically stable, have no more than a moderate aerodynamic drag, and often maintain a specific orientation over wide ranges of flight conditions.

Examples of towed expendable systems now in the research and development phase include the government sponsored Tracor Aerospace "Big Boy" RF decoy and the Tracor Internal Research and Development (IR&D) funded Tracor Aerospace towed IR decoy. While RF and IR guided missiles are the greatest threat to an aircraft today, in the future, MMW and laser guided missiles will also be of concern. It is likely that towed decoy techniques would be expanded to counter those threats. {1:36-39}

CHAPTER V

DESIGN CONCERNS FOR TOWED DECOY SYSTEMS

Advances in electronic technology have enhanced the development of decoys which can be made small and effective. But while development risks have been reduced in the design and production of electronic systems, many functions of a towed decoy system are mechanical and aerodynamic. The three major areas of design risk are the mechanical aspects of the decoy dispenser subsystem, the aerodynamics and flight characteristics of the decoy, and the final flight testing of all resulting designs.

Whether designed to counter RF or IR threats, decoy systems come in two general types. The first employs a retrievable decoy. This system requires a dispenser which uses an electric or ram-air motor and a towline reel to reel out the decoy when needed and reel it in when no longer needed. The towline itself must be strong enough to survive the aircraft's flight envelope, and it may be required to provide electrical power and/or control information to the decoy. Because the reel out and reel in process is done fairly slowly, many of the mechanical and aerodynamic problems expected with a retrievable system lie in the transition area in the turbulent air near the aircraft. To minimize these problems, the system designer may decide to either locate the dispenser on the aircraft in a position where the decoy won't damage either the aircraft or itself as it is reeled out/in, or provide additional mechanical arms or tracks to guide the decoy when near the aircraft.

The second type of decoy system employs a non-retrievable decoy. This system requires a dispenser which uses a pyrotechnic device or squib to explosively deploy the decoy fast enough to clear the aircraft as it deploys. The dispenser, as in the retrievable decoy case, contains towline and a reel, but there the similarity ends. Instead of a motor to control the deployment speed of the decoy, there would be a friction based braking subsystem. This subsystem must allow the decoy to deploy fast enough to be effective, but slow enough so the towline does not snap while bringing the decoy to a stop.

There are design risks to both deployment types. The retrievable system allows recovery of the decoy if it is not damaged during the mission. This is good if the decoy is very expensive or if it is too large to allow carrying a significant number of backups, but there is a penalty in weight, space and power to carry around the motor and additional mechanical assemblies. There is also the chance of damage to the decoy and/or aircraft during retrieval. The non-retrievable decoy system may be best used when decoy costs are low, and the decoys are small enough to allow adequate backups. The major penalties are that the braking system must be reliable, the towline may need to be stronger, and there is a drag penalty for dragging around a decoy when it is not needed.

Operational vulnerability of the decoy itself and the estimated employment of the threat will be key drivers as to which type of deployment system is selected. A non-retrievable system may be desired if the decoy is large, if it is highly vulnerable to near misses, or if the threat is likely to fire closely timed salvos of missiles at the aircraft. In the case where the decoy is itself vulnerable to near misses, it is important to have adequate backups. In the other case where missiles are launched in salvos, if the "first" missile in the salvo kills the decoy, it is important to be able to sever what may be left of the damaged decoy, and deploy and activate the next decoy before the "second" missile of the salvo can acquire and destroy the aircraft.

Once deployed, decoy aerodynamic flight characteristics is the second major area of technical risk. Things towed by airplanes in the past tended to be fairly large and were required to have stable flight characteristics only in relatively level flight and at selected airspeeds and altitudes. Towed decoys must be aerodynamically stable and usually maintain a particular orientation throughout all aircraft flight conditions. In addition to maintaining stability and orientation, the decoy may be required to "fly" above or below the centerline of the aircraft.

Decoy stability, or the amount of movement it makes in yaw, pitch and roll can drive the towline strength requirement as an unstable decoy would be more likely to fatigue and break the towline. Stability and orientation are important for decoys, like RF decoys, that radiate energy in only certain polarizations. A rotation of an RF decoy's transmit antenna by 90 degrees, may result a mismatch in polarization between the decoy transmit antenna and the missile seeker's receive antenna. The result could be for the missile seeker to reacquire and guide to the aircraft rather than the decoy. An IR decoy will not be degraded by minor orientation changes as its energy is not polarized.

Decoys that "fly" above the aircraft centerline tend to be more effective against missiles that attack the aircraft from above, and decoys that "fly" below the aircraft centerline tend to be more effective against missiles that attack the aircraft from below. Consider the following very simplified example. Our aircraft is flying straight at an attacking aircraft 10,000 meters away and 4000 meters above us. Our decoy is deployed 300 meters behind us and is "flying" 10 meters below us. Assume that we make no maneuvers and that the missile fired against us flies in a straight line toward the decoy. Let us also assume that the missile travels so fast that our aircraft basically stands still in the air prior to detonation. Looking up the given numbers (a=4000, b=10,000, c=-10, and f=300) in Appendix A, Table 1, column "h2" reveals that the missile will pass directly over our aircraft by 99.5 meters. For the same parameters, Appendix A, Table 1, column "h2" shows that we would gain an additional 18.2 meters of miss distance if the decoy flew 10 meters (c=+10 instead of -10) above our aircraft.

Miss distances for missiles launched from below us, like a direct ascent SAM, can be obtained from the lower half of Appendix A, Tables 1-4. Note that a negative miss distance means that the attacking missile passed below us. Table 2 can be used to show the effect of the attacking missile being launched further from us. As expected, a launch from further away results in lower miss distances. In the case of an attack from the rear, the miss distances in Tables 3 and 4 are based on an additional assumption that the missile does not detonate or strike the decoy and continues to fly straight on past the decoy. While these scenarios are much simplified, the tables are useful to show which parameters most directly influence miss distance.

Appendix C shows a derivation of formulas used in creating Tables 1-4 in Appendix A. While not proved in either appendix, it may be of interest that the tables can also be used to compute miss distances on intercepts from directions not directly from the nose or tail. For example, consider a missile launched from a range of 10,000 meters, 2,000 meters above our altitude and 4,000 meters off to one side. Let us also assume our decoy is 10 meters below and 300 meters behind our aircraft. Using the vertical parameters (a=2000, b=10,000, c=-10, f=300), Appendix A, Table 1, column "h2" results in a vertical miss distance of 47.6 meters. Using the horizontal parameters (a=4000, b=10,000, c=-10, f=300) Appendix A, Table 1, column "h2" results in a horizontal miss distance of 99.5 meters. The total miss distance is 110.3 meters using the formula:

$$x = \sqrt{y^2 + z^2}$$

Where:

x = Total miss distance

y = Vertical miss distance

z = Horizontal miss distance

The third major area of technical risk is flight testing of the towed expendable system. As mentioned earlier, electronic technology poses less of a problem than does mechanical and aerodynamic technologies for towed decoy systems. Looking at each of the three areas, electronics, mechanics and aerodynamics, I see the following types of problems encountered during final system testing.

From an electronic standpoint, likely problem areas in the dispenser are packaging, cooling, and electrical power. Packaging refers to creating a specific black box or Line Replaceable Unit (LRU) that has to fit in a specific small space in, or on, the aircraft. This can be a problem if the dispenser is being designed for multiple types of aircraft. Each may have its own unique problem areas that combine to make the dispenser very difficult to design. Packaging electronics too tightly can lead to the second problem, cooling. Cooling of electronic components, including self-test of RF decoys still inside the dispenser can be accomplished by thermal transfer directly to the aircraft external surface or some form of ram-air cooling. Electrical power can be a problem when retrofitting a new dispenser into an existing airframe. Often different voltages and/or higher currents are needed than existing wiring harnesses can safely provide. Each of these problems can pose design challenges, but in general their solutions are not of the sort that cannot be adequately tested by ground tests.

In the decoy, likely problem areas also include packaging and cooling, but here are new problems with transmit power, antenna design, environmental qualification. As with the dispenser, decoy electrical designs can be tested with high confidence in laboratory and ground qualification tests. Antenna patterns, for instance, will be much the same in the air as they are when measured by a good ground antenna range. Likewise, environmental qualification tests such are vibration, salt fog, driving rain, rain erosion, etc. can be suitably conducted on the ground.

Unlike dispenser and decoy electrical problems, however, dispenser mechanical and decoy aerodynamic problems cannot always be suitably tested on the ground. In designing an aircraft, designers will usually develop a computer aided design, test that design with various computer programs that will predict inflight performance and stability, build and "fly" a scale model in a wind tunnel, and then if all is successful, develop a full size prototype that can be flown by test pilots.

In designing the decoy and dispenser, however, this process can be quite challenging. Reasons include lack of computer programs and experimental flight data for objects as small as the decoy, and lack of wind tunnel facilities that will allow ejecting or flying a tethered expendable, and any that might allow it are rarely long enough for a full length deployment of the towline. Also, laboratory qualification tests that actually predict how the system will function in the air are difficult to develop. As a result, system prototypes flown in a flight test program may induce aerodynamic effects quite different from the production article.

Many times, this is due to the prototype being made larger or of different materials than planned for the production article. Sometimes this is done intentionally to allow special instrumentation to be installed to measure vibration, temperature, voltage levels, etc. No matter how well intentioned, until real production articles are delivered and flown, confidence in early flight tests may be premature.

The bottom line on flight testing is that testing needs to be conducted throughout the flight envelope of each aircraft type that intend to use the system. If there is a requirement for a fighter aircraft to dispense a decoy at Mach 1.5 at 500 ft above sea level, or during a 9 G turn, or while doing evasive maneuvers, it needs to be tested by a real production article.

In this chapter, I analyzed and assessed the generic characteristics and the key design concerns of both retrievable and non-retrievable towed decoy systems. The three major areas of risk addressed were the mechanical aspects of the decoy dispenser subsystem, the aerodynamics and flight characteristics of the decoy, and the final flight testing of all resulting designs. Recapping my conclusions for each category:

a. Dispenser mechanical -- I concluded that especially for the retrievable decoy dispenser, selective location of the dispenser and employment of mechanical arms or tracks can minimize problems as the decoy transitions through the turbulent air near the aircraft; that the biggest advantage of the retrievable decoy system is the possibility of reusing the same decoy throughout that mission and future missions; and that some of the advantages in selecting a non-retrievable decoy system include lower system weight, space and power requirements, being able to carry more decoys, simplicity inside the dispenser, and faster response to threat missiles launched in salvos.

b. Decoy aerodynamics and flight characteristics -- I concluded that RF decoys particularly, need to be very stable in yaw, pitch and roll, to keep antenna orientations matched with missile seeker antennas; and that missile miss distances may be increased by building decoys with variable flight characteristics (eg. "flying" a decoy above the towing aircraft when it is attacked by a threat from above, or "flying" below the aircraft when attacked from below).

c. Decoy and dispenser flight testing -- I concluded that laboratory and ground environmental/qualification tests can reveal the system design acceptability in the areas of packaging, cooling and electrical power. For dispenser mechanical and decoy aerodynamic concerns, however, representative tests can only be performed in flight. Also, when flight testing is done, articles as close to the production article as possible must be used, and flight testing must cover the full flight regime of all aircraft types/variants expecting to use the system.

CHAPTER VI

OPERATIONAL CONCERNS FOR TOWED DECOY SYSTEMS

Operational concerns for employing towed decoys fall into three categories: safety, security and effectiveness. Under the category of safety, I include safety to own aircraft, safety to other aircraft, and safety to ground personnel/systems. It is likely for a single decoy to weigh as little as a half a pound or as much as 10's of pounds. Considering damage to own aircraft from a non-retrievable, or explosively deployed decoy, damage could result from heat build-up of a hang-fire (a decoy that sticks in the dispenser tube and does not exit), too rapid an ejection due to a "hot" pyro, or too slow an ejection due to a "cold" pyro. Damage to own aircraft from a retrievable, or reel out/in, decoy could result from failure of the mechanical arm holding the decoy away from the aircraft or failure of the motor mechanism during reel in/out operations.

Specifically, for the non-retrievable decoy system, a hang-fire is not likely to cause any damage because the amount of gunpowder needed in the pyro is generally equivalent to a small firecracker. A "hot" or "cold" decoy ejection could cause the decoy to strike an aircraft surface, but good planning in locating the dispenser, and good quality control in pyro manufacturing and in the build-up phase of the dispenser tube, reel, and brake components should minimize this danger.

Integration of the decoy deployment logic with the aircraft digital avionics would help by prohibiting launches when the aircraft is conducting flight activity where an anticipated worst case "hot" and "cold" launch might be dangerous to the aircraft.

For the retrievable decoy system, the mechanical aspects of the arm and motor are likely to be the highest failure items. Here again, location of the dispenser and good quality control in the fabrication process can minimize problems. One additional area that needs to be evaluated for own aircraft safety is whether aircraft flight will be degraded if a massive system failure occurs and all decoys are launched and towed at the same time. Normal design measures to protect electronic systems from lightning strikes, directed energy weapons and electromagnetic pulses should reduce this possibility.

Safety concerns for other aircraft (here concerned only for those flying in formation) are more critical. Unlike untethered expendables which generally fall away and down from tactical aircraft, the deployed towed expendable continues to trail the towing aircraft. Since these decoys weigh one-half to tens of pounds, and are on a towline that can be hundreds of feet long, there is a large potential for danger to friendly aircraft flying in formation. Decoys that have been damaged or that have deployed improperly (stabilizing fins not deployed for example) will be aerodynamically unstable and would be expected to "cone" or flop around on the end of the towline. The coning movement of aerodynamically unstable decoys is dependent on the cause of the instability and the airspeed of the towing aircraft, but can be expected to be equal to, or greater than, ten percent of the towline length. To ensure aircrew safety from unstable decoys, it is essential to reevaluate formation flying and air-to-air tactics.

Safety for ground personnel, property and systems is also critical. One of the disadvantages of the non-retrievable decoy is that it can never be recovered in flight. As a result, each decoy intentionally or unintentionally deployed must be cut loose, or severed, from the aircraft before landing. To add to this problem, there is always the possibility that the towline of either type of decoy (retrievable or non-retrievable) will fatigue and break during launch, while under normal towing, or for the retrievable decoy, during recovery. As a rule, one must be prepared to lose a decoy any time the system is armed. To prevent danger to ground personnel or systems during peacetime training, training should be done over areas known to be uninhabited. Also, post mission safe drop areas should be identified and a wingman or crewmember in a safety aircraft needs to visually check that planned retrieval or severing processes are successful prior to landing.

The second category of operational concern is security. This includes protection of classified RF and IR decoy deployment logic, electronics, capabilities, modes of operation, and signatures. This falls into two general categories, physical security and electronic security.

Physical security includes actions to protect all hardware comprising the off-board expendable system. Even recovery of a single "spent" decoy may be enough for a potential enemy to reverse engineer the article and determine major capabilities and vulnerabilities of the expendable system. First, all assets must be handled as controlled items when in supply channels, maintenance channels, and when installed on the aircraft. Second, when operating the system for peacetime training, one of the following must be done: train (launch, tow, retrieve/sever) over areas where expended decoys can be recovered; train over areas where decoys will never be found (eg. over large, deep bodies of water); or train with non-operational training decoys. Of the above, the most secure method of training is to use a training decoy over a body of water where there there is high confidence that a severed or lost decoy will sink and not be found. As this alternative means that two systems with different capabilities must be built, stocked and maintained, this may be unacceptable from a cost point of view. The next most secure method of training would be to only deploy and train with operational decoys over water.

Electronic security measures for testing and training are equally difficult. They include operating in areas and at times when foreign SIGnals INTelligence (SIGINT) collection assets are not present, employing encryption of telemetry and range tracking signals, and operating only with nonrepresentative training assets. Security is essential to protect the decoy system capabilities. For the peacetime training scenario, I prefer a combined solution in which the real decoys are operated over deep ocean water (here you do not need recovery teams and there is little chance of spent decoys washing ashore), where provisions are made for on-board recorders to record any decoy performance and status needed for post-mission review, and all range telemetry including actual locations of expendable carrier aircraft and its threat are encrypted.

The third and final operational concern is effectiveness. As stated earlier, an off-board expendable system is a self-protection countermeasure. Once enabled, its sole job is to draw the threat missile far enough away from the aircraft so that even if the missile detonates, the aircraft will be outside the kill radius of the missile. This particular area can best be addressed by a comprehensive test program during the early stages of a development program. In the next chapter, acquisition concerns, I relate a four phase process which I feel is a low risk approach to ensure that the system remains effective even after procured and operational.

In this chapter, I analyzed and assessed the key operational concerns of both retrievable and non-retrievable towed decoy systems. The three major areas of risk addressed were safety, security and effectiveness. Recapping my conclusions for each category:

a. Safety -- I concluded that safety must be considered for the towing aircraft, for other friendly aircraft flying in formation, and for ground personnel and systems. For safety to the towing aircraft, I concluded that there is little concern if decoy launch logic is integrated with aircraft digital avionics and if good practices are followed during the design phase and the manufacturing quality control phase. For safety to other aircraft, I concluded that due to the length of the towline, the weight/size of the towed decoy, and the possibility of an unstable decoy, it is critical that formation flying and air-to-air tactics be evaluated to ensure aircrew safety. For safety to ground personnel and systems, I concluded that aircrew training is going to be more difficult to conduct due to the possibility of unintentional deployments, random towline fatigue and failures, and the need for visual safety checks for the towing aircraft prior to landing.

b. Security -- I concluded that both physical and electronic security must be maintained. For physical security, I concluded that the best means of protecting the physical hardware, exclusive of expended decoys, is to treat all expendable system components as controlled hardware when in supply channels, maintenance channels, and installed on the aircraft. To protect intentionally or unintentionally expended decoys, the best procedure is to only train over large, deep bodies of water like an ocean. This will provide the best probability that spent decoys will not be found and exploited through reverse engineering. For electronic security, I concluded that training should only be accomplished in areas and at times when foreign SIGnals INTelligence (SIGINT) collectors are not present. Also, maximum use of on-board data recorders, secure communications and encryption of instrumentation signals is required.

c. Effectiveness -- I concluded that the towed decoy system, like any other ECM system, is of little operational value if it does not function as designed. To ensure that the system is truly effective, I have recommended a four step test philosophy. This approach is described in detail in the chapter on acquisition concerns.

CHAPTER VII

ACQUISITION CONCERNS FOR THE TOWED DECOY SYSTEMS

The towed decoy concept of self-protection countermeasures is unique and potentially very effective against modern air and surface launched, guided missiles. A system like this is of little value, though, if it is not bought at a cost effective price, or if it cannot be tested to prove that it remains effective against the threat even after deployed. These then are the main concerns that must be addressed during the acquisition process.

The first area of acquisition concern is system cost. If the system unit cost is too high, then it could mean that only limited numbers of aircraft can be outfitted with this self-protection system. Even worse, those aircraft receiving the system may be unable to train with the system for lack of assets. To evaluate the potential market for towed decoy expendable systems, let us review where the US employs self-protection expendable systems today. Assuming that aircraft currently using AN/ALE-39,40 and 45 expendable self-protection countermeasures systems (see Chapter 4 for lists) are eventually equipped with a towed decoy system, we are looking at an initial procurement of about 7500 towed decoy systems. This number comes from summing current utilization of about 3000 AN/ALE-39 systems {5:1}, about 4000 AN/ALE-40 systems (2500 current systems plus plans to acquire an additional 1500) {6:5}, and about 500 AN/ALE-45 systems {7:1}. Add to this the quantities needed each year for spares, the maintenance and supply pipelines, training, and follow on test and evaluation, and the quantity makes a substantial leap.

Past development of non-expendable countermeasures, such as on-board jamming equipment, has been largely the responsibility of each aircraft prime contractor. As a result there tends to be little commonality from one aircraft type to another for on-board ECM systems. The expendables community, however, has established a precedent for maximum commonality. Already, most major US aircraft are covered by just the three expendable systems described above and in the Department of Defense quest for even more commonality, the AN/ALE-47 program has been directed to ensure maximum tri-service commonality, AND, to be box-for-box replaceable with current generation Army, Navy and Air Force expendable systems. {8:2}

System acquisition costs can be divided into development (also called research and development) and procurement (also called production) costs. The development costs of acquiring hardware that is common to many different types of aircraft will run higher than the development cost of a system designed for single type of aircraft. This is due primarily to multiple and conflicting requirements in areas like environmental and performance specifications, and costly flight test programs to ensure integration and performance. Because each military service and each developer of aircraft identified for the common system will always need unique or special requirements, early development costs of a common system are likely to remain higher than for the specifically designed systems. While there is little likelihood of reducing these higher early development costs, the average unit production cost and the long term cost of ownership tends to be less for the common system. Several reasons that contribute to reduced long term ownership costs include:

a. Warranties can be better defined and applied due to larger quantities of hardware produced.

b. Common support equipment will lead to more efficient depot repair.

c. Procurement and stocks of spare parts will be more efficient and higher quantity discounts will be obtained from parts suppliers and vendors.

d. Initial and spare shipsets and components will have a lower average unit cost due to learning curve benefits.

f. Better competition and lower costs on defense contracts due to higher quantities.

g. Besides cost, an unmeasurable but very real long term benefit of commonality, is the increased operational performance that comes with being able to interchange systems and/or components between different types of aircraft.

Consider the following simplified example which demonstrates how long term acquisition costs are affected by production learning curves. We would like to procure a towed decoy expendable system, or systems, which are interchangeable with existing AN/ALE-39,40 and 45 expendable systems and we envision two scenarios. The first is that separate systems will be procured to replace each of the AN/ALE-39,40 and 45 systems, the second is that one common system will be procured to replace these systems. Learning curve costs (Tables 1-4 in Appendix B) were estimated based on the following assumptions:

a. The "cumulative average" learning curve (9:23) is used, and system quantities are derived from past experience with the AN/ALE-39 (3000 systems), the AN/ALE-40 (4000 systems) and the AN/ALE-45 (500 systems).

b. The common system (Table 1), the separate system to replace the AN/ALE-39 (Table 2), and the separate system to replace the AN/ALE-40 (Table 3) are based on four annual lots starting in fiscal year (FY) 1990. The separate system to replace the AN/ALE-45, because of its low total quantity, (Table 4) is based on two annual lots starting in FY 90.

c. Separate system quantities for each lot are the product of the author and assume a fairly normal ramp-up to rate production. Common system quantities for each lot are a sum of the three separate system lot quantities.

d. In each table, there is only one design and the contract may be to sole source or multiple competing contractors. Note that because of competition, the same production learning curve used for a sole source contractor generally works out to be equally valid for a design manufactured by multiple competing contractors.

e. Learning curve calculation assumptions are that all first unit costs are the same ($200,000), all learning curve slopes are the same (90%), and inflation is a constant three percent per year.

f. The learning curve represents cost only and does not account for any profits which may also be due to the contractors.

Evaluating the data in Tables 1-4, one can see that the cumulative weighted cost for the common system is $405.7 million and the total cumulative weighted cost of the three separate systems is $465.1 million. It then costs $59.4 million, or 14.6 percent more, to have the three contractors produce their own design. (9:23) With this in mind, I feel that there is substantial incentive to evaluate for any real systems, the procurement of common, single design systems, much like currently being done in the AN/ALE-47 program.

The second major area of acquisition concern is system testing. During the procurement cycle, a set of specifications will be developed for the towed decoy system. These specifications will include environmental and performance requirements among other things. Consider the following simplified and certainly incomplete performance requirements which could be levied on a countermeasures system:

a. Threats to counter: eg. SA-10 (RF), SA-9 (IR), Foxbat (RF/IR), etc.

b. Azimuth of coverage: eg. 45 degrees left through 45 degrees right of the nose and tail.

c. Elevation of coverage: eg. 30 degrees below through 30 degrees above aircraft centerline for the required azimuth coverage.

d. Maximum time to launch and activate next decoy: eg. 5 seconds.

The first thing noticed about these requirements is that they are very difficult to evaluate in the dynamic air-to-air and surface-to-air threat environment. If we were lucky enough to have the actual threat systems and their associated missiles, safety and prudence would prevent us from launching them at our manned aircraft. Even if we disregarded safety and did launch them, it is nearly impossible to achieve a statistically significant kill to miss ratio. How then can the system be tested during development and throughout its operational life to ensure that it has and retains an assured capability?

Often, in the rush to get technology from the drawing board to the field, shortcuts in the development process are taken. One accepted form of taking shortcuts is called 'concurrency'. Basically concurrency means that all the normal acquisition steps are accomplished, but sometimes in parallel rather than sequentially. While this process can significantly reduce the amount of time it takes to get hardware into the field, it also exposes the government to higher cost, schedule and technical risks. One recent example of concurrency is the B-1B bomber production program. In this program, full scale development ran concurrently with production. When full scale development problems were experienced with the AN/ALQ-161 ECM system, the production line continued for the basic airframe, and aircraft were delivered without a working defensive avionics system. Later, when full scale development problems were worked out, each of the already delivered aircraft had to be retrofitted with ECM kits. Was this necessarily a bad way to do business? On the plus side, aircraft deliveries were made far earlier than if production had started after full scale development and crewmembers could fly the aircraft and get a head-start or training and weapon system certification. On the minus side, it looked bad to the public and certainly cost more to do retrofitting than if no problems had occurred during concurrent activities. Basically, the government evaluated the needs and risks, and decided that early delivery was worth increased risks associated with concurrency.

For development and procurement of towed decoy expendable systems, I feel that the risks associated with system integration and performance tests (ground, laboratory and flight) are so high that concurrency should be avoided or minimized. To this end, I recommend an incremental testing <u>process</u> which would consist of four distinct phases. These phases correlate roughly to the standard research and development phases of: 6.1 (basic research), 6.2 (exploratory development), 6.3 (advanced development), and 6.4 (full scale development), but I do not intend that they have to be funded from those program elements or accomplished by other than program office contractors.

The key to success in system testing is employing the 6.1 through 6.4 thought process or approach to evaluate plans and problems. Too often, early or rushed testing results in either a success which looks good at the time but is not repeatable, or a failure which due to over optimism, results in too little data to know why. The four phase approach which I feel minimizes these occurrences is described below and I give short examples of how to apply each phase to the development and testing of a towed decoy system.

a. Phase 1 (like 6.1, basic research) -- Computer simulation. Key activities in this phase include developing representative scenarios (including tactics, maneuvers, different threats etc.), creation of detailed computer models of these scenarios, and conducting computer simulations. The value of computer simulation is that this is an area in which one can test all aircraft configurations, all aircraft flight profiles, and even oddball, worst case scenarios that are impossible to test in-flight. From these simulations, a performance database is developed and evaluated against any preliminary test data (rarely does one find a system for which some amount of mock-up testing has not already been done at either contractor or government expense). I call this whole process verification, or testing the results for reasonableness. In this phase, it is very important that the aircraft "user" and the aircraft prime contractor remain actively involved in the development of operationally realistic scenarios. Selection and evaluation of the "wrong" scenarios can lead to poor system performance tradeoffs or a need to repeat this phase much later in the system development and testing process. Either of these conditions can lead to significant cost, risk and schedule slips.

The developing program office will have to determine how much simulation it can afford to do (or not to do), but all critical subsystems should be considered. Obvious simulations include initial threat detection, miss distance calculation for all required threats and scenarios, decoy radiation patterns, and decoy aerodynamic stability. Less obvious simulations include decoy ejection velocity, decoy acceleration and velocity profiles during deployment, and temperature effects of the towing aircraft exhaust plume on the decoy.

To summarize, the primary goal of phase one is to verify that the computer simulations are reasonable based on data existing on other programs, general technology, and previous prototype testing. The outputs of this phase include comprehensive databases and information leading to system performance tradeoffs and a rationale for mock-up/prototype development, and detailed system and subsystem test plans.

b. Phase 2 (like 6.2, exploratory development) -- Laboratory testing. The key activity in this phase is to conduct adequate controlled testing to validate phase one simulations. I call this process, validation of the previous phase. During this phase, the contractor should identify test procedures for key performance, risk and system tradeoffs that need to be tested. Examples may include decoy wind tunnel testing, radiation pattern testing, RF or IR effectiveness against each threat, decoy static firing to determine ejection velocities, and the normal pre-qualification tests for temperature, humidity, shock, vibration, etc. Government as well as contractor test facilities should be considered. The government facilities (ranges, chambers, tunnels) tend to be cheaper to use and better instrumented than similar contractor ones, but can be more difficult to schedule into. Government facilities also lend additional credence to results by their independence from the contractor.

The goal of this phase is to conduct laboratory tests with actual items to validate the databases and simulations developed in phase one. Note that one is able to run far more variations on the possible scenarios in phase one than in phase two (and as you will see shortly, more in phase two than phase three, and more in phase three than phase four). If laboratory results are not exactly as predicted by phase one, now is the time to correct and redo phase one for that failure. Outputs of this phase are validated simulations and databases, and laboratory verification that the initial system components are functioning as desired.

c. Phase 3 (like 6.3, advanced development) -- Nondestructive flight testing. Key activities in this phase include flying the decoy system against simulated airborne and ground threats to validate the lab tests. There are numerous government test assets that should be considered for this phase. One representative example for RF decoys is the AIM-7M Goldenbird pod. This is an AIM-7M missile that retains a functioning seeker, but has been highly instrumented and hard-wired to an F-14 or F-15 carrier aircraft. In operation, the aircraft carrying the Goldenbird pod flies in formation with another aircraft that acts as the target tracking and illumination aircraft. The target tracking aircraft first finds and locks-on to its target, another aircraft carrying the decoy system. When the pilot of the aircraft with the Goldenbird pod gets a good seeker lock-on, he flies a high speed intercept, following directions from the AIM-7M seeker display in the cockpit. Instrumentation telemetered to the ground and/or recorded on-board the aircraft is used to determine the effectiveness of the countermeasure. Other airborne and ground test systems of this type are available to evaluate decoy effectiveness for other frequencies and weapon characteristics.

Throughout the nondestructive flight testing phase, as many data points as possible should be collected that match scenarios in phases one and two. The overall purpose of this phase is to validate the laboratory testing of phase two and to gain confidence that the system functions as designed. The output of this phase is a decision to either repeat earlier phases or to proceed to phase four.

d. Phase 4 (like 6.4, full scale development) -- Limited live fire tests. The key activity in this phase is to fire live missiles (usually US missiles that are accepted surrogates for non-US missile threats) against drones (unmanned aircraft). These drones may have to be modified to have a radar or infrared signature equal to or greater than the worst case proposed carrier aircraft. This live fire activity needs to be done in two phases. First, non-warhead, instrumented missiles should be used. This helps to validate the results from previous phases without as much chance of losing the drone. After confidence is gained in the decoy system, a mix of live warhead and non-warhead missiles can be used to obtain statistically significant results.

As before, as many data points as possible should be obtained using the same scenarios used in previous phases. The key to success is to build good databases early, and continue to validate their accuracy. The payoff using this approach is that during the development and manufacturing process, many seemingly inconsequential changes are introduced. With validated simulations and laboratory tests, the very expensive flight testing may not have to be repeated.

In this chapter, I analyzed and assessed concerns associated with system cost and with system testing. Recapping my conclusions for each category:

a. System cost -- Naturally I concluded that the lower the cost the better, and to support the view that maximum commonality across all three services would decrease long term ownership costs, I presented an example which demonstrated how costs are decreased by taking advantage of the manufacturing learning curve.

b. System testing -- I concluded that a four phase test process can reduce risks and costs during the acquisition process. Basically this process consists of sequentially stepping through simulation, laboratory tests, non 'estructive flight tests and then live fire flight tests. The key to this approach is to build upon and validate all essential data from a previous phase before moving on to the next phase. Too often, in the rush to get hardware into the "field", too many shortcuts are taken during testing. This can result in having either a success or a failure that cannot be explained.

CHAPTER VIII

SUMMARY

Towed decoy systems are currently in various stages of research and development. This study discusses two main types of these systems. The first is based on a retrievable decoy with a dispenser that reels out and reels in the decoy, and second is based on a non-retrievable decoy with a dispenser that fires out the decoy then severs its towline when finished with it. Even though the first system recovers its decoy, both types of systems are considered "self-protection" expendables. Upon a comparison with previous expendable systems and tow target systems, the author feels that there are design, operational and acquisition concerns that should be addressed during the acquisition cycle. This study identifies these concerns, provides an assessment as to why each is important, and concludes with recommendations on how to resolve or minimize them during the development process.

In this paper, I described the subsystems that makes up a non-towed, expendable system, and how that system differs from a next generation, towed decoy, expendable system. I also discussed what makes the off-board expendable countermeasures system important and how it relates to past experience with aerial tow targets. The real purpose, however, was to analyze and assess design, operational, and acquisition concerns for this relatively new type of active off-board expendable ECM. With respect to these concerns, I summarize as follows:

a. <u>Design concerns:</u> The three major areas of risk addressed were the mechanical aspects of the decoy dispenser subsystem, the aerodynamics and flight characteristics of the decoy, and the final flight testing of all resulting designs. Recapping my conclusions for each category:

(1.) Dispenser mechanical -- I concluded that especially for the retrievable decoy dispenser, selective location of the dispenser and employment of mechanical arms or tracks can minimize problems as the decoy transitions through the turbulent air near the aircraft; that the biggest advantage of the retrievable decoy system is the possibility of reusing the same decoy throughout that mission and future missions; and that some of the advantages in selecting a non-retrievable decoy system include lower system weight, space and power requirements, being able to carry more decoys, simplicity inside the dispenser, and faster response to threat missiles launched in salvos.

(2.) Decoy aerodynamics and flight characteristics -- I concluded that RF decoys particularly, need to be very stable in yaw, pitch and roll, to keep antenna orientations matched with missile seeker antennas; and that missile miss distances may be increased by building decoys with variable flight characteristics (eg. "flying" a decoy above the towing aircraft when it is attacked by a threat from above, or "flying" below the aircraft when attacked from below).

(3.) Decoy and dispenser flight testing -- I concluded that laboratory and ground environmental/qualification tests can reveal the system design acceptability in the areas of packaging, cooling and electrical power. For dispenser mechanical and decoy aerodynamic concerns, however, representative tests can only be performed in flight. Also, when flight testing is done, articles as close to the production article as possible must be used, and flight testing must cover the full flight regime of all aircraft types/variants expecting to use the system.

b. Operational concerns: The three major areas of risk addressed were safety, security and effectiveness. Recapping my conclusions for each category:

(1.) Safety -- I concluded that safety must be considered for the towing aircraft, for other friendly aircraft flying in formation, and for ground personnel and systems. For safety to the towing aircraft, I concluded that there is little concern if decoy launch logic is integrated with aircraft digital avionics and if good practices are followed during the design phase and the manufacturing quality control phase. For safety to other aircraft, I concluded that due to the length of the towline, the weight/size of the towed decoy, and the possibility of an unstable decoy, it is critical that formation flying and air-to-air tactics be evaluated to ensure aircrew safety. For safety to ground personnel and systems, I concluded that aircrew training is going to be more difficult to conduct due to the possibility of unintentional deployments, random towline fatigue and failures, and the need for visual safety checks for the towing aircraft prior to landing.

(2.) Security -- I concluded that both physical and electronic security must be maintained. For physical security, I concluded that the best means of protecting the physical hardware, exclusive of expended decoys, is to treat all expendable system components as controlled hardware when in supply channels, maintenance channels, and installed on the aircraft. To protect intentionally or unintentionally expended decoys, the best procedure is to only train over large, deep bodies of water like an ocean. This will provide the best probability that spent decoys will not be found and exploited through reverse engineering. For electronic security, I concluded that training should only be accomplished in areas and at times when foreign signal intelligence (SIGINT) collectors are not present. Also, maximum use of on-board data recorders, secure communications and encryption of instrumentation signals is required.

(3.) Effectiveness -- I concluded that the towed decoy system, like any other ECM system, is of little operational value if it does not function as designed. To ensure that the system is truly effective, I have recommended a four step test philosophy. This approach is described in detail in Chapter 7.

c. <u>Acquisition concerns:</u> The two major areas of risk addressed were system cost and system testing. Recapping my conclusions for each category:

(1.) System cost -- Naturally I concluded that the lower the cost the better, and to support the view that maximum commonality across all three services would decrease long term ownership costs, I presented an example which demonstrated how costs are decreased by taking advantage of the manufacturing learning curve.

(2.) System testing -- I concluded that a four phase test process can reduce risks and costs during the acquisition process. Basically this process consists of sequentially stepping through simulation, laboratory tests, non-destructive flight tests and then live fire flight tests. The key to this approach is to build upon and validate all essential data from a previous phase before moving on to the next phase. Too often, in the rush to get hardware into the "field", too many shortcuts are taken during testing. This can result in having either a success or a failure that cannot be explained.

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Miss Distance Table

a	b	e	f1	h1 (miss)	f2	h2 (miss)	f3	h3 (miss)
4000	10000	30	500	204.6	300	135.4	100	62.8
4000	10000	20	500	195.8	300	126.6	100	54.5
4000	10000	10	500	186.9	300	117.6	100	45.9
4000	10000	0	500	178.0	300	108.6	100	36.8
4000	10000	−10	500	169.0	300	99.5	100	27.4
4000	10000	−20	500	160.0	300	90.2	100	17.7
4000	10000	−30	500	150.8	300	80.8	100	7.5
2000	10000	30	500	121.5	300	85.5	100	47.7
2000	10000	20	500	112.2	300	76.2	100	38.5
2000	10000	10	500	102.9	300	66.7	100	29.0
2000	10000	0	500	93.6	300	57.2	100	19.4
2000	10000	−10	500	84.2	300	47.6	100	9.6
2000	10000	−20	500	74.7	300	38.0	100	−0.4
2000	10000	−30	500	65.3	300	28.3	100	−10.6
0	10000	30	500	28.6	300	29.1	100	29.7
0	10000	20	500	19.0	300	19.4	100	19.8
0	10000	10	500	9.5	300	9.7	100	9.9
0	10000	0	500	0.0	300	0.0	100	0.0
0	10000	−10	500	−9.5	300	−9.7	100	−9.9
0	10000	−20	500	−19.0	300	−19.4	100	−19.8
0	10000	−30	500	−28.6	300	−29.1	100	−29.7
−2000	10000	30	500	−65.3	300	−28.3	100	10.6
−2000	10000	20	500	−74.7	300	−38.0	100	0.4
−2000	10000	10	500	−84.2	300	−47.6	100	−9.6
−2000	10000	0	500	−93.6	300	−57.2	100	−19.4
−2000	10000	−10	500	−102.9	300	−66.7	100	−29.0
−2000	10000	−20	500	−112.2	300	−76.2	100	−38.5
−2000	10000	−30	500	−121.5	300	−85.5	100	−47.7
−4000	10000	30	500	−150.8	300	−80.8	100	−7.5
−4000	10000	20	500	−160.0	300	−90.2	100	−17.7
−4000	10000	10	500	−169.0	300	−99.5	100	−27.4
−4000	10000	0	500	−178.0	300	−108.6	100	−36.8
−4000	10000	−10	500	−186.9	300	−117.6	100	−45.9
−4000	10000	−20	500	−195.8	300	−126.6	100	−54.5
−4000	10000	−30	500	−204.6	300	−135.4	100	−62.8

Definitions:

All Distances/Measurements in Meters.
a = Altitude of Missile at Launch, Above (+)/Below (−) Target Aircraft.
b = Missile Range to Target at Launch, in front (+)/behind (−).
e = Decoy distance above (+)/Below (−) Target Aircraft.
f = Towline Length.
h = Missile Miss Distance, Point of Closest Approach.
Miss above Target (+). Miss Below Target (−).

TABLE 1: Front Miss Distances

Miss Distance Table

a	b	e	f1	h1 (miss)	f2	h2 (miss)	f3	h3 (miss)
4000	20000	30	500	124.3	300	86.7	100	47.9
4000	20000	20	500	114.9	300	77.2	100	38.7
4000	20000	10	500	105.3	300	67.6	100	29.2
4000	20000	0	500	95.8	300	58.0	100	19.5
4000	20000	−10	500	86.2	300	48.3	100	9.7
4000	20000	−20	500	76.5	300	38.5	100	−0.4
4000	20000	−30	500	66.8	300	28.7	100	−10.7
2000	20000	30	500	77.6	300	58.7	100	39.2
2000	20000	20	500	67.9	300	49.0	100	29.5
2000	20000	10	500	58.3	300	39.2	100	19.8
2000	20000	0	500	48.5	300	29.4	100	9.9
2000	20000	−10	500	38.8	300	19.6	100	0.0
2000	20000	−20	500	29.1	300	9.7	100	−10.1
2000	20000	−30	500	19.3	300	−0.1	100	−20.3
0	20000	30	500	29.3	300	29.6	100	29.9
0	20000	20	500	19.5	300	19.7	100	19.9
0	20000	10	500	9.8	300	9.9	100	10.0
0	20000	0	500	0.0	300	0.0	100	0.0
0	20000	−10	500	−9.8	300	−9.9	100	−10.0
0	20000	−20	500	−19.5	300	−19.7	100	−19.9
0	20000	−30	500	−29.3	300	−29.6	100	−29.9
−2000	20000	30	500	−19.3	300	0.1	100	20.3
−2000	20000	20	500	−29.1	300	−9.7	100	10.1
−2000	20000	10	500	−38.8	300	−19.6	100	0.0
−2000	20000	0	500	−48.5	300	−29.4	100	−9.9
−2000	20000	−10	500	−58.3	300	−39.2	100	−19.8
−2000	20000	−20	500	−67.9	300	−49.0	100	−29.5
−2000	20000	−30	500	−77.6	300	−58.7	100	−39.2
−4000	20000	30	500	−66.8	300	−28.7	100	10.7
−4000	20000	20	500	−76.5	300	−38.5	100	0.4
−4000	20000	10	500	−86.2	300	−48.3	100	−9.7
−4000	20000	0	500	−95.8	300	−58.0	100	−19.5
−4000	20000	−10	500	−105.3	300	−67.6	100	−29.2
−4000	20000	−20	500	−114.9	300	−77.2	100	−38.7
−4000	20000	−30	500	−124.3	300	−86.7	100	−47.9

Definitions:

All Distances/Measurements in Meters.
a = Altitude of Missile at Launch, Above (+)/Below (−) Target Aircraft.
b = Missile Range to Target at Launch, in front (+)/behind (−).
e = Decoy distance above (+)/Below (−) Target Aircraft.
f = Towline Length.
h = Missile Miss Distance, Point of Closest Approach.
Miss above Target (+), Miss Below Target (−).

TABLE 2: Front Miss Distances

Miss Distance Table

a	b	e	f1	h1 (miss)	f2	h2 (miss)	f3	h3 (miss)
4000	−10000	30	500	−164.7	300	−85.3	100	−7.6
4000	−10000	20	500	−174.6	300	−95.1	100	−18.0
4000	−10000	10	500	−184.4	300	−104.8	100	−27.9
4000	−10000	0	500	−194.0	300	−114.4	100	−37.5
4000	−10000	−10	500	−203.6	300	−123.8	100	−46.6
4000	−10000	−20	500	−213.1	300	−133.1	100	−55.4
4000	−10000	−30	500	−222.5	300	−142.2	100	−63.7
2000	−10000	30	500	−72.0	300	−30.0	100	10.8
2000	−10000	20	500	−82.4	300	−40.3	100	0.4
2000	−10000	10	500	−92.7	300	−50.5	100	−9.8
2000	−10000	0	500	−103.0	300	−60.6	100	−19.8
2000	−10000	−10	500	−113.3	300	−70.6	100	−29.6
2000	−10000	−20	500	−123.5	300	−80.6	100	−39.2
2000	−10000	−30	500	−133.6	300	−90.5	100	−48.5
0	−10000	30	500	31.6	300	30.9	100	30.3
0	−10000	20	500	21.1	300	20.6	100	20.2
0	−10000	10	500	10.5	300	10.3	100	10.1
0	−10000	0	500	0.0	300	0.0	100	0.0
0	−10000	−10	500	−10.5	300	−10.3	100	−10.1
0	−10000	−20	500	−21.1	300	−20.6	100	−20.2
0	−10000	−30	500	−31.6	300	−30.9	100	−30.3
−2000	−10000	30	500	133.6	300	90.5	100	48.5
−2000	−10000	20	500	123.5	300	80.6	100	39.2
−2000	−10000	10	500	113.3	300	70.6	100	29.6
−2000	−10000	0	500	103.0	300	60.6	100	19.8
−2000	−10000	−10	500	92.7	300	50.5	100	9.8
−2000	−10000	−20	500	82.4	300	40.3	100	−0.4
−2000	−10000	−30	500	72.0	300	30.0	100	−10.8
−4000	−10000	30	500	222.5	300	142.2	100	63.7
−4000	−10000	20	500	213.1	300	133.1	100	55.4
−4000	−10000	10	500	203.6	300	123.8	100	46.6
−4000	−10000	0	500	194.0	300	114.4	100	37.5
−4000	−10000	−10	500	184.4	300	104.8	100	27.9
−4000	−10000	−20	500	174.6	300	95.1	100	18.0
−4000	−10000	−30	500	164.7	300	85.3	100	7.6

Definitions:

All Distances/Measurements in Meters.
a = Altitude of Missile at Launch, Above (+)/Below (−) Target Aircraft.
b = Missile Range to Target at Launch, in front (+)/behind (−).
e = Decoy distance above (+)/Below (−) Target Aircraft.
f = Towline Length.
h = Missile Miss Distance, Point of Closest Approach.
Miss above Target (+), Miss Below Target (−).

TABLE 3: Rear Miss Distances

Miss Distance Table

a	b	e	f1	h1 (miss)	f2	h2 (miss)	f3	h3 (miss)
4000	-20000	30	500	-70.2	300	-29.6	100	10.8
4000	-20000	20	500	-80.3	300	-39.7	100	0.4
4000	-20000	10	500	-90.4	300	-49.7	100	-9.8
4000	-20000	0	500	-100.5	300	-59.7	100	-19.7
4000	-20000	-10	500	-110.5	300	-69.6	100	-29.5
4000	-20000	-20	500	-120.5	300	-79.4	100	-39.0
4000	-20000	-30	500	-130.4	300	-89.2	100	-48.3
2000	-20000	30	500	-20.3	300	0.2	100	20.5
2000	-20000	20	500	-30.6	300	-10.0	100	10.2
2000	-20000	10	500	-40.8	300	-20.2	100	0.1
2000	-20000	0	500	-51.0	300	-30.3	100	-10.0
2000	-20000	-10	500	-61.2	300	-40.4	100	-19.9
2000	-20000	-20	500	-71.4	300	-50.4	100	-29.8
2000	-20000	-30	500	-81.5	300	-60.4	100	-39.5
0	-20000	30	500	30.8	300	30.5	100	30.1
0	-20000	20	500	20.5	300	20.3	100	20.1
0	-20000	10	500	10.3	300	10.2	100	10.0
0	-20000	0	500	0.0	300	0.0	100	0.0
0	-20000	-10	500	-10.3	300	-10.2	100	-10.1
0	-20000	-20	500	-20.5	300	-20.3	100	-20.1
0	-20000	-30	500	-30.8	300	-30.5	100	-30.1
-2000	-20000	30	500	81.5	300	60.4	100	39.5
-2000	-20000	20	500	71.4	300	50.4	100	29.8
-2000	-20000	10	500	61.2	300	40.4	100	19.9
-2000	-20000	0	500	51.0	300	30.3	100	10.0
-2000	-20000	-10	500	40.8	300	20.2	100	-0.1
-2000	-20000	-20	500	30.6	300	10.0	100	-10.2
-2000	-20000	-30	500	20.3	300	-0.2	100	-20.5
-4000	-20000	30	500	130.4	300	89.2	100	48.3
-4000	-20000	20	500	120.5	300	79.4	100	39.0
-4000	-20000	10	500	110.5	300	69.6	100	29.5
-4000	-20000	0	500	100.5	300	59.7	100	19.7
-4000	-20000	-10	500	90.4	300	49.7	100	9.8
-4000	-20000	-20	500	80.3	300	39.7	100	-0.4
-4000	-20000	-30	500	70.2	300	29.6	100	-10.8

Definitions:

All Distances/Measurements in Meters.
a = Altitude of Missile at Launch. Above (+)/Below (-) Target Aircraft.
b = Missile Range to Target at Launch. in front (+)/behind (-).
e = Decoy distance above (+)/Below (-) Target Aircraft.
f = Towline Length.
h = Missile Miss Distance, Point of Closest Approach.
Miss above Target (+), Miss Below Target (-).

TABLE 4: Rear Miss Distances

BASE YEAR =1989 APPROPRIATION =3010
All Costs in Base Year, Millions

FILE: CUM-AVE.T-1 MAY 90	INPUTS	CUM QUAN	LOT AVE COST (1)	CUM AVE COST (2)	LOT TOTAL COST (3)	CUM TOTAL COST (4)	THEN YEAR	FACTOR	LOT WTD COST	CUM WTD COST
LOT 1:		850	0.07	0.07	61.0	61.0	1990	1.00000	61.0	61.0
QUANTITY	850									
SLOPE (eg .90)	0.900									
1st UNIT COST	0.200									
LOT 2: QUANTITY	2050	2900	0.05	0.06	111.7	172.6	1991	1.03000	115.0	176.0
LOT 3: QUANTITY	2300	5200	0.05	0.05	110.6	283.3	1992	1.06000	117.3	293.3
LOT 4: QUANTITY	2300	7500	0.04	0.05	103.2	386.4	1993	1.09000	112.5	405.7
LOT 5: QUANTITY	0									
LOT 6: QUANTITY	0									
LOT 7: QUANTITY	0									

3010 TABLE

THEN YEAR	WTD INFL FACTOR
1990	1.0000
1991	1.0300
1992	1.0600
1993	1.0900
1994	1.1200
1995	1.1500
1996	1.1800
1997	1.2100
1998	1.2400
1999	1.2700
2000	1.3000
2001	1.3300
2002	1.3600
2003	1.3900
2004	1.4200
2005	1.4500

NOTE (1): Lot Average Cost is the average cost of the units in that lot.

LACn = LTCn / Qn

where:

LACn = Lot Average Cost of Lot n
LTCn = Total Lot Cost of Lot n (See note 3 below)
Qn = Quantity of units in Lot n

NOTE (2): Cum Ave Cost is the average cost of all units through that lot.

CACn = CTCn / Qc

where:

CACn = Cumulative Average Cost of all units through Lot n.
CTCn = Cum Total Cost of all units through Lot n. (See note 4 below)
Qc = Cumulative Quantity of all units through Lot n.

NOTE (3): Lot Total Cost is the total cost of units in Lot n.

LTCn = CTCn - CTC(n-1)

where:

CTCn = Cumulative Total Cost of units through Lot n (See note 4 below)
CTC(n-1) = Cum Total of units through Lot (n-1) (See note 4 below)

NOTE (4): Cum Total Cost is the cumulative cost of all units through Lot n.

CTCn = FUC *(Qc^(b+1))   [or CTCn = A*N^(b+1) in more common terms]

where:

CTCn = Cum Total Cost of units through Lot n
Qc = Cumulative Quantity of units through Lot n
b = A constant such that SLOPE = 100 * (2^b)

and:

SLOPE = Slope of the Learning Curve Line
b = (Ln (SLOPE / 100)) / Ln (2)

TABLE 1: CUMULATIVE QUANTITY FOR COMMON SYSTEM

BASE YEAR =1989 APPROPRIATION =3010
All Costs in Base Year, Millions

3010 TABLE

FILE: CUM-AVE.T-2 MAY 90	INPUTS	CUM QUAN	LOT AVE COST (1)	CUM AVE COST (2)	LOT TOTAL COST (3)	CUM TOTAL COST (4)	THEN YEAR	FACTOR	LOT WTD COST	CUM WTD COST	THEN YEAR	WTD INFL FACTOR
LOT 1:		300	0.08	0.08	25.2	25.2	1990	1.00000	25.2	25.2	1990	1.0000
QUANTITY	300										1991	1.0300
SLOPE (eg .90)	0.900										1992	1.0600
1st UNIT COST	0.200										1993	1.0900
											1994	1.1200
LOT 2: QUANTITY	700	1000	0.06	0.07	44.8	70.0	1991	1.03000	46.1	71.3	1995	1.1500
											1996	1.1800
LOT 3: QUANTITY	1000	2000	0.06	0.06	56.0	126.0	1992	1.06000	59.3	130.7	1997	1.2100
											1998	1.2400
LOT 4: QUANTITY	1000	3000	0.05	0.06	51.7	177.7	1993	1.09000	56.3	187.0	1999	1.2700
											2000	1.3000
LOT 5: QUANTITY	0										2001	1.3300
											2002	1.3600
LOT 6: QUANTITY	0										2003	1.3900
											2004	1.4200
LOT 7: QUANTITY	0										2005	1.4500

NOTE (1): Lot Average Cost is the average cost of the units in that lot.

LACn = LTCn / Qn

where:

LACn = Lot Average Cost of Lot n
LTCn = Total Lot Cost of Lot n (See note 3 below)
Qn = Quantity of units in Lot n

NOTE (2): Cum Ave Cost is the average cost of all units through that lot.

CACn = CTCn / Qc

where:

CACn = Cumulative Average Cost of all units through Lot n.
CTCn = Cum Total Cost of all units through Lot n. (See note 4 below)
Qc = Cumulative Quantity of all units through Lot n.

NOTE (3): Lot Total Cost is the total cost of units in Lot n.

LTCn = CTCn - CTC(n-1)

where:

CTCn = Cumulative Total Cost of units through Lot n (See note 4 below)
CTC(n-1) = Cum Total of units through Lot (n-1) (See note 4 below)

NOTE (4): Cum Total Cost is the cumulative cost of all units through Lot n.

CTCn = FUC *(Qc^(b+1))   [or CTCn = A*N^(b+1) in more common terms]

where:

CTCn = Cum Total Cost of units through Lot n
Qc = Cumulative Quantity of units through Lot n
b = A constant such that SLOPE = 100 * (2^b)

and:

SLOPE = Slope of the Learning Curve Line
b = (Ln (SLOPE / 100)) / Ln (2)

TABLE 2: AN/ALE-39 QUANTITIES

BASE YEAR =1989 APPROPRIATION =3010
All Costs in Base Year, Millions

3010 TABLE

FILE: CUM-AVE.T-3 MAY 90	INPUTS	CUM QUAN	LOT AVE COST (1)	CUM AVE COST (2)	LOT TOTAL COST (3)	CUM TOTAL COST (4)	THEN YEAR	FACTOR	LOT WTD COST	CUM WTD COST	THEN YEAR	WTD INFL FACTOR
LOT 1:		400	0.08	0.08	32.2	32.2	1990	1.0000	32.2	32.2	1990	1.0000
QUANTITY	400										1991	1.0300
SLOPE (eg .90)	0.900										1992	1.0600
1st UNIT COST	0.200										1993	1.0900
											1994	1.1200
LOT 2: QUANTITY	1000	1400	0.06	0.07	60.9	93.1	1991	1.0300	62.7	94.9	1995	1.1500
											1996	1.1800
LOT 3: QUANTITY	1300	2700	0.05	0.06	69.4	162.5	1992	1.0600	73.6	168.5	1997	1.2100
											1998	1.2400
LOT 4: QUANTITY	1300	4000	0.05	0.06	64.3	226.8	1993	1.0900	70.1	238.5	1999	1.2700
											2000	1.3000
LOT 5: QUANTITY	0										2001	1.3300
											2002	1.3600
LOT 6: QUANTITY	0										2003	1.3900
											2004	1.4200
LOT 7: QUANTITY	0										2005	1.4500

NOTE (1): Lot Average Cost is the average cost of the units in that lot.

$LACn = LTCn / Qn$

where:

- $LACn$ = Lot Average Cost of Lot n
- $LTCn$ = Total Lot Cost of Lot n (See note 3 below)
- Qn = Quantity of units in Lot n

NOTE (2): Cum Ave Cost is the average cost of all units through that lot.

$CACn = CTCn / Qc$

where:

- $CACn$ = Cumulative Average Cost of all units through Lot n.
- $CTCn$ = Cum Total Cost of all units through Lot n. (See note 4 below)
- Qc = Cumulative Quantity of all units through Lot n.

NOTE (3): Lot Total Cost is the total cost of units in Lot n.

$LTCn = CTCn - CTC(n-1)$

where:

- $CTCn$ = Cumulative Total Cost of units through Lot n (See note 4 below)
- $CTC(n-1)$ = Cum Total of units through Lot (n-1) (See note 4 below)

NOTE (4): Cum Total Cost is the cumulative cost of all units through Lot n.

$CTCn = FUC * (Qc^{(b+1)})$ [or $CTCn = A*N^{(b+1)}$ in more common terms]

where:

- $CTCn$ = Cum Total Cost of units through Lot n
- Qc = Cumulative Quantity of units through Lot n
- b = A constant such that $SLOPE = 100 * (2^{b})$

and:

SLOPE = Slope of the Learning Curve Line

$b = (\ln(SLOPE / 100)) / \ln(2)$

TABLE 3: AN/ALE-40 QUANTITIES

BASE YEAR =1989 APPROPRIATION =3010
All Costs in Base Year, Millions

3010 TABLE

FILE: CUM-AVE.T-4 MAY 90	INPUTS	CUM QUAN	LOT AVE COST (1)	CUM AVE COST (2)	LOT TOTAL COST (3)	CUM TOTAL COST (4)	THEN YEAR	FACTOR	LOT WTD COST	CUM WTD COST	THEN YEAR	WTD INFL FACTOR
LOT 1:		150	0.09	0.09	14.0	14.0	1990	1.0000	14.0	14.0	1990	1.0000
QUANTITY	150										1991	1.0300
SLOPE (eg .90)	0.900										1992	1.0600
1st UNIT COST	0.200										1993	1.0900
											1994	1.1200
LOT 2: QUANTITY	350	500	0.07	0.08	24.9	38.9	1991	1.0300	25.6	39.6	1995	1.1500
											1996	1.1800
LOT 3: QUANTITY	0										1997	1.2100
											1998	1.2400
LOT 4: QUANTITY	0										1999	1.2700
											2000	1.3000
LOT 5: QUANTITY	0										2001	1.3300
											2002	1.3600
LOT 6: QUANTITY	0										2003	1.3900
											2004	1.4200
LOT 7: QUANTITY	0										2005	1.4500

NOTE (1): Lot Average Cost is the average cost of the units in that lot.

LACn = LTCn / Qn

where:

LACn = Lot Average Cost of Lot n
LTCn = Total Lot Cost of Lot n (See note 3 below)
Qn = Quantity of units in Lot n

NOTE (2): Cum Ave Cost is the average cost of all units through that lot.

CACn = CTCn / Qc

where:

CACn = Cumulative Average Cost of all units through Lot n.
CTCn = Cum Total Cost of all units through Lot n. (See note 4 below)
Qc = Cumulative Quantity of all units through Lot n.

NOTE (3): Lot Total Cost is the total cost of units in Lot n.

LTCn = CTCn - CTC(n-1)

where:

CTCn = Cumulative Total Cost of units through Lot n (See note 4 below)
CTC(n-1) = Cum Total of units through Lot (n-1) (See note 4 below)

NOTE (4): Cum Total Cost is the cumulative cost of all units through Lot n.

CTCn = FUC *(Qc^(b+1)) [or CTCn = A*N^(b+1) in more common terms]

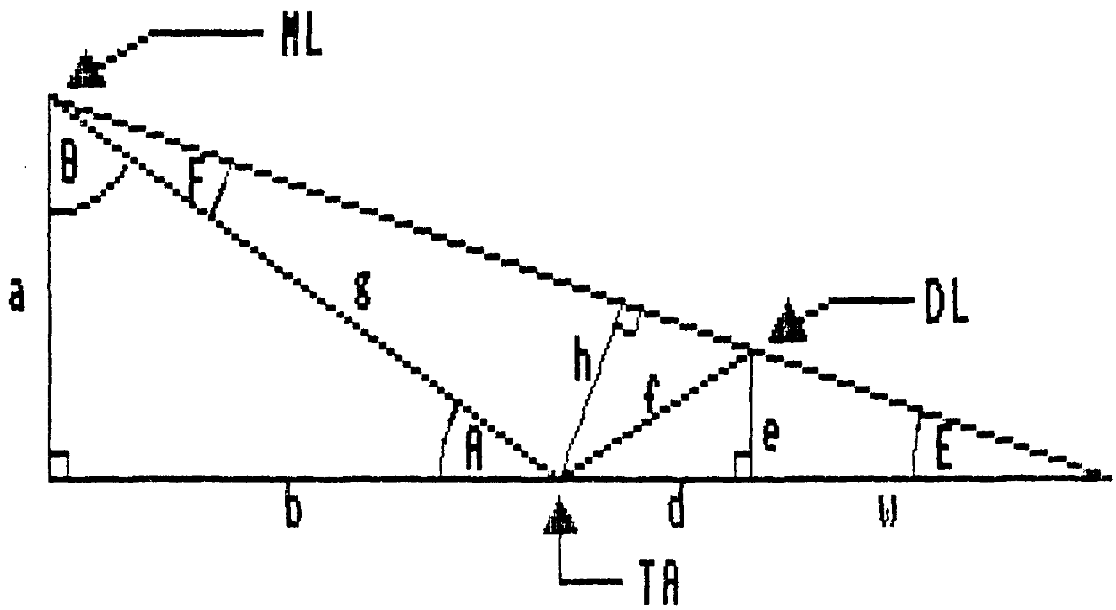
where:

CTCn = Cum Total Cost of units through Lot n
Qc = Cumulative Quantity of units through Lot n
b = A constant such that SLOPE = 100 * (2^b)

and:

SLOPE = Slope of the Learning Curve Line
b = (Ln (SLOPE / 100)) / Ln (2)

TABLE 4: AN/ALE-45 QUANTITIES



Definitions:

All distances in meters.
All angles in degrees.

ML = Missile Launch Point.
TA = Target Aircraft Location.
DL = Decoy Location.

a = Altitude of Missile at Launch above (+)/below (-) Target.
b = Missile Range at Launch in Front of (+) or Behind (-) Target.
e = Decoy Distance Above (+) or Below (-) Target.
f = Towline Length.
h = Missile Closest Approach, Above (+) or Below (-) Target.

Derivation of "h", Missile Closest Approach, Given Values for a, b, e and f:

Step 1. d^2 + e^2 = f^2
Therefore d = (f^2 - e^2)^1/2

Step 2. Angle B = ArcTan (b/a)

Step 3. g = b/(sin Angle B)

Step 4. Tan Angle E = e/w = a/(b+d+w)
Therefore w = (e*(b+d))/(a-e)

Step 5. Angle E = ArcTan (e/w)
Therefore Angle E = ArcTan (a-e)/(b+d)

Step 6. Angle F = 90 deg - Angle E - Angle B

Step 7. h = Missile Closest Approach = g*(sin Angle F)

Missile Miss Distance Formulas